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Greater adaptivity or greater control? Adaptation of IOR portfolios in response to technological change

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ABSTRACT

This paper addresses the question of how firms accomplish the strategic task of adapting their entire set of IORs (interorganizational relationships) to changing environmental conditions. To study this, we move beyond the focus on collaboration with individual partners (the dyadic perspective) that has been the dominant emphasis in the literature until now. Instead, we view the firms' portfolios through the lens of the different modes of IOR engaged in (licensing agreements, non-equity alliances, venture capital investments, minority investments, joint ventures, and mergers & and acquisitions). We study the role of environmental change within the high-tech setting of the bio-pharmaceutical industry and distinguish between industry technological change and firm-specific technological change. In doing so, we rely on prospect theory to theorize how firms' perceptions of environmental change in terms of a looming loss or a potential gain affect their risk-bearing, how this leads them to adjust their IOR portfolio diversity, and how these adjustments get implemented at the mode level. Whereas most of our hypotheses were confirmed by the study, a key unexpected finding was that firms respond to both types of technological change through stronger forms of adaptation than theoretically anticipated. Firms adapt to industry technological change through an increase in the diversity of their portfolio of IORs and by churning it up, which leads to a loosening of control at the individual mode level but greater adaptivity at the portfolio level. When facing firm-specific change instead, they adapt by reducing portfolio diversity, while cutting back on collaboration across five out of the six modes. Our findings both contribute to the literature on organizational adaptation, interfirm collaboration, and IOR portfolios and provide a greater behavioral understanding of network change.

1. Introduction

For firms in technology-intensive industries, external collaboration has become a pervasive phenomenon, since it generally brings positive effects for their overall performance and innovation performance in particular. Collaboration offers a number of substantive benefits formed by the possibilities for mutual knowledge sharing, combining complementary skills, scale economies in research, and sharing costs and risks (Ahuja, 2000a; Gilsing et al., 2008; Hagedoorn, 1993; Phelps, 2010; Sabidussi et al., 2014). This resonates with the dominant, static view in the large volume of literature on interorganizational relationships (IORs) and interfirm collaboration, which has predominantly emphasized the stable value derived from these activities and focused on performance outcomes (Tasselli et al., 2015; Wassmer, 2010).

More recently, however, an emerging view in the literature argues that to ensure their IORs remain beneficial, firms need to adapt and renew their portfolio of such relationships on an ongoing basis (Ahuja et al., 2012; Powell et al., 2005). This is also in line with some recent success stories on innovation collaboration, such as Procter & Gamble's connect and develop program, IBM's emerging business areas, and LEGO's open innovation strategy—examples of three different companies that adapted their IOR portfolio and thus enhanced their ability to create new innovations and secure future competitiveness (Foss et al., 2012). In line with this, recent studies have called for an investigation of the antecedents of firms' IOR portfolios and the development of a dynamic perspective (Ahuja et al., 2012; Kantola et al., 2017; Phelps et al., 2012; Tatarinowitz et al., 2016).

In technology-intensive environments, especially, ongoing technological change can quickly render existing knowledge and skills obsolete, implying that the IORs in place lose their value and requiring

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that a firm adapt and renew its IOR portfolio (Powell et al., 2005). This ties into a broader debate in the literature on the need for ongoing organizational adaptation, the single most important factor for long-term survival (Haveman, 2003; Hrebiniak and Joyce, 1985; Meyer et al., 1990; O'Reilly and Tushman, 2008; Siggelkow and Levinthal, 2003). The purpose of organizational adaptation is to maintain or improve fit with changing environmental conditions in the aim of enhancing performance and ensuring future survival (Hrebiniak and Joyce, 1985; Meyer et al., 1990).

In the growing literature on this topic, the main emphasis has been on adjustments to a firm's internal organizational attributes, such as changes to: managerial roles (Stan and Puranam, 2017), individual learning (Aggarwal et al., 2017), service offerings (Ruef, 1997), strategy and structure (Jennings and Seaman, 1994), internal routines (Yi et al., 2016), multi-level organizational dynamics (Dattee and Barlow, 2017), or identity (Dutton and Dukerich, 1991). Given the prevalence of IORs for modern firms these days, the question arises as to what extent firms are also adapting core *external* organizational attributes to changing environmental conditions. Although there is an emerging understanding of the adaptation at the individual partnership level (e.g., Gulati, 1995), our current understanding of how firms accomplish the major strategic task of adapting their external organization of IORs as a whole remains in its infancy.

We will study the role of environmental change within the context of a high-technology setting, that of the bio-pharmaceutical industry, distinguishing between industry technological change (defined as technological turbulence at the industry level) and firm-specific technological change (defined as technological turbulence at the firm level). The distinction is based on similar distinctions made with regard to uncertainty in general, specifically between an entire industry's uncertainty/market level uncertainty and a firm's specific uncertainty (e.g., Beckman, Haunschild, & Philips, 2004; Cuypers and Martin, 2010; Li, 2008). In one earlier study, Beckman et al. (2004) considered how firms respond to uncontrollable market uncertainty and found that they adapted by reinforcing their standing network through the formation of additional alliances with existing partners.

Uncontrollability of environmental uncertainty is generally linked to a threat-rigidity response, which leads us to expect that firms would indeed strengthen their existing IORs since these are likely to be of assistance in times of uncertainty (e.g., Granovetter, 1982; Krackhardt (1992); Williamson, 1981). Another key form of environmental change besides uncontrollable external events is that imposed by technological change, something that may be more within the bounds of discretion for individual firms, yet carries risks of loss or potential gain (Chattopadhyay et al., 2001; Greve, 1998; Ocasio, 1995; Tushman and Anderson, 1986). This raises the question of how firms adjust their entire set of IORs in response to such technological change. How differently do firms respond and do they do it by exerting more control or becoming more adaptive? The purpose of this study is to address this important issue by shedding more light on the extent to which firms accomplish this by adjusting their external organization made up of IORs.

This focus on how firms adjust their external organization implies that we need to move beyond the examination of the collaboration with individual partners (dyadic perspective) that has dominated the literature until now. Instead, the lens that we will apply is formed by a company's IOR portfolio. Firms use different modes of IORs—such as licensing agreements, non-equity alliances, corporate venture capital investments (CVCs), minority investments, joint ventures (JVs), and mergers and acquisitions (M&As)—to collaborate with others. Because of differences between these modes and their advantages and disadvantages, firms employ a combination of them simultaneously, producing a varied portfolio (Carayannopoulos and Auster, 2010; Kantola et al., 2017; Keil et al., 2008).

We will study firms' adaptations to their portfolio of IORs at two different levels of analysis. First, we will focus on the portfolio level by considering the degree of diversity. We define portfolio diversity as the diversity of IOR modes that a firm employs at a certain point in time, and we will investigate whether firms adapt to environmental change by either increasing or decreasing their portfolio diversity.[1] Second, we will consider the individual mode level by studying how firms implement these adaptations to their IOR portfolio diversity by adjusting the number of newly initiated IORs or varying the portfolio's composition in terms of type (e.g., more licensing agreements at the expense of JVs or vice versa).

For the purposes of our analysis, traditional transaction costs economics (TCE) theory would appear less well equipped for understanding this question of how firms adjust their portfolio of IORs for two reasons. First, TCE focuses on maximizing efficiency in an individual transaction or partnership, rather than on maximizing the joint efficiency of a set of transactions or partnerships. This implies that TCE carries less relevance when analyzing the adaptation of a combination—a portfolio—of multiple IOR modes, which is the focus of this study. The second reason has to do with our focus on environmental change. To the extent that environmental change, as formed by technological change, increases, the future becomes more difficult to predict. As we will further outline below, TCE has proven less equipped to understanding governance choices under environmental conditions of unpredictability. TCE's core prediction is that increasing uncertainty leads to more hierarchical and control-oriented forms of collaboration. However, this runs counter to an emerging stream in the literature that argues, and demonstrates, that under increasing uncertainty due to change (technological and otherwise), firms resort to more adaptive forms of organizing (Folta, 1998; Santoro and McGill, 2005; Li and Li, 2010).

Moreover, the impact of environmental change is not necessarily unequivocal for firms, and as such managers must interpret its implications more than with other forms of change. This suggests the need for a more behavioral perspective that helps us analyze how firms adapt their external organization based on their understanding of different types of environmental change. The behavioral perspective that we will rely on in this study is that of prospect theory. As we argue below, prospect theory is useful in this context because it explains how executives' perceptions of environmental change in terms of a looming loss or a potential gain affect their risk-bearing (Anderson and Nichols, 2007; Bromiley, 2010; Kahneman and Tversky, 1979; Pérez-Nordtvedt et al., 2014; Wiseman and Gomez-Mejia, 1998) and how this then affects their decisions and actions on adjusting their external organization of IORs.

Below, we first outline our theory and hypotheses. This is followed by a description of a new dataset—comprising over 8400 IORs belonging to the 282 largest firms in the pharmaceutical biotechnology industry over a period from 1990 until 2006—that we developed to capture the various types of technological change and investigate our hypotheses. We end the paper with a number of conclusions, as well as a broader discussion of how our study informs the wider literature.

2. Conceptual background and hypotheses

2.1. Interorganizational relationships

The benefits of IORs have been well documented in the literature (e.g., Phelps et al., 2012; Kantola et al., 2017). As argued and shown, such relationships offer opportunities for knowledge recombination and scale economies, but also for spreading risks and hedging bets (e.g.,

[1] Note that the focus of this paper is on the diversity of the IOR modes used by the focal firm. This diversity is the result of the variety of modes a firm uses and hence does not refer to another concept called partner diversity (which focuses on different *partner types*, such as buyers, suppliers, research institutes, etc.; see e.g., De Leeuw et al., 2014).

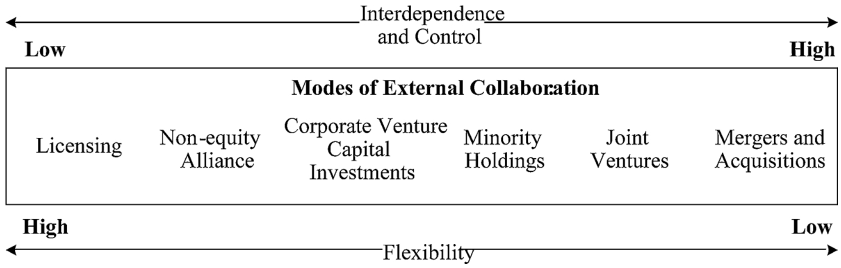

Fig. 1. IOR modes and their levels of interdependence, control, and flexibility.

Ahuja, 2000a; Kogut, 1991). To accomplish these objectives, firms have come to rely on different modes of IORs, such as licensing agreements, non-equity alliances, CVC investments, minority investments, JVs, and M&As.

A firm's IOR portfolio will include all of these major modes. Although each mode has specific advantages and characteristics, Hagedoorn (1993) has shown that they differ in their degree of interdependence between the partnering firms. As such, each individual relationship may differ in terms of the level of flexibility and degree of control (Barringer and Harrison, 2000; Keil et al., 2008; Van de Vrande et al., 2009), which allows us to draw a general distinction between two categories of modes for external collaboration. Fig. 1, summarizes the IOR modes in relation to their level of interdependence, control, and flexibility.

On the one hand, there are more arm's-length, market-like forms of IORs that offer flexibility. Typically, these are formed through licensing agreements, non-equity alliances, or corporate venturing activities. On the other hand, there are more integrated IOR modes representing hierarchical forms of collaboration that offer more control. Typically, those modes are formed through minority investments, JVs, and M&As. Because of differences between these modes of IORs and their advantages and disadvantages, firms employ a combination of them simultaneously (Carayannopoulos and Auster, 2010; Keil et al., 2008) and it has been argued that such diversity contributes to a firm's innovation success (Duysters and Lokshin, 2011; Goerzen and Beamish, 2005; Hashai et al., 2015; Jiang et al., 2010; Lee et al., 2017; Sabidussi et al., 2014).

Despite the fact that firms rely on a combination of IOR modes, the dominant emphasis in the literature has been on governance choices for one particular form or another; for example, the conditions under which equity-based collaboration might be preferred over more arm's-length relations with a prospective partner (e.g., Santoro and McGill, 2005). The key theoretical perspective in such studies is that of transaction cost economics (TCE), in which the primary focus is on choosing a governance form that reduces uncertainty and economizes on transaction costs (e.g., frequency of exchange, degree of asset specificity, and behavioral uncertainty of a partner). The general principle through TCE is that when transaction costs increase, more integrated forms are preferable for controlling the hazards of collaboration (Williamson, 1981).

Within the context of technological collaboration, transaction costs also come from the uncertainty caused by technological complexity. Technological complexity can arise, among other things, from a large distance between partners in their respective fields of technological specialization or when collaboration takes place in complex technological domains. The ensuing increase in transaction costs makes equity forms preferable to non-equity ones for bridging any large technological distance between partners (Colombo, 2003) or acquisitions preferable to alliances for collaborating in complex technological domains (Carayannopoulos and Auster, 2010). In line with this, it has also been argued that equity forms are more suitable for highly complex collaborations, such as ones with a broad product, technology, or activity scope or with a strong technology focus (Folta, 1998; Gulati, 1995; Gulati and Singh, 1998; Hagedoorn, 1993), or in cases where complementary assets for commercializing new innovations are specialized rather than generic (Teece, 1986).

However, apart from being related to technological complexity, uncertainty can also follow from *environmental change*. Environmental change can vary from static to dynamic and refers to the extent to which the external environment remains basically the same or is in a process of discontinuous or continuous change (Dess and Beard, 1984; Duncan, 1972). To the extent that an environment is in a state of flux, it becomes increasingly difficult to predict the future. This makes environmental change, or unpredictability, a generally stronger source of environmental uncertainty than environmental complexity (Duncan, 1972).[2] Whereas environmental complexity such as technological complexity can be computed or reasonably estimated, the amount of uncertainty or unpredictability due to environmental change is difficult to calculate or compute ex ante.[3]

As a consequence, executives managing IORs will generally be less able to come to a reasonably accurate estimation of environmental change. Instead, they need to rely on an interpretation of the change and try to establish what it means. This suggests that TCE is less useful for understanding governance choices under changing conditions and implies a need for relying instead on a more behavioral perspective that can provide an understanding of how firms adapt their external organization based on their interpretation of different types of environmental change. The behavioral perspective that we will rely on in this study is formed by prospect theory. As we will argue below, prospect theory is useful in this context for explaining how executives' perceptions of environmental changes in terms of a looming loss or potential gain affect their risk-bearing (Anderson and Nichols, 2007; Bromiley, 2010; Kahneman and Tversky, 1979; Pérez-Nordtvedt et al., 2014; Wiseman and Gomez-Mejia, 1998) and how this affects their decisions and actions on adjusting their IOR portfolio.

2.2. Types of technological change: industry vs. firm-specific

Technological change can be a particularly disruptive force,

[2] The literature on unravelling environmental uncertainty generally makes a distinction between two dimensions of environmental complexity (Dess and Beard, 1984; Duncan, 1972): 1) the simple–complex dimension takes the number of factors, and their interdependency, into account in decision making; 2) the static–dynamic dimension looks at the degree to which these factors in the environment remain the same over time or are in a continual state of change. The static–dynamic dimension of the environment is generally a stronger contributor to uncertainty in decision making than the simple–complex dimension (Dess and Beard, 1984; Duncan, 1972).

[3] This stands in contrast to TCE, where the implicit idea is that the degree of uncertainty due to complexity can generally be calculated as both frequency of exchange and asset specificity, which can be quite accurately computed, whereas the behavioral uncertainty of one specific partner can generally also be estimated reasonably well, for example based on the structural embeddedness effects in networks (Gulati and Garguilo, 1999). Hence, the general idea is that based on this information, a rational governance choice can be made (Williamson, 1981).

especially in technology-intensive industries. In this context, it is defined as the change in a focal firm's technological environment (Song et al., 2005), whereby we also make a distinction between two types of technological change: industry and firm-specific. Industry technological change refers to changes in technology at the industry level and indicates a degree of change across a range of technology classes for a group of firms in an industry. By contrast, firm-specific technological change refers to a firm's degree of change in its development of new technologies relative to industry-level change. This implies that the higher the degree of firm-specific change a company is experiencing, the more it will change its technologies relative to the rest of the industry.

Here, our study builds upon the stream of literature that investigates firms' IOR choices as a response to change and the uncertainty related to change. Cuypers and Martin (2010), for example, found that exogenous uncertainty leads to a smaller share of ownership in foreign JVs, while endogenous uncertainty does not. Beckman et al. (2004) found that market uncertainty leads to a reinforcing of the alliance and JV networks, while firm-specific uncertainty leads to a broadening of the network. Li (2008) found that market uncertainty results in a delay in venture capital staging investments, whereas project-specific uncertainty results in greater investment. While investigating licensing, minority equity investments, and JVs, Santoro and McGill (2005) found that partner and task uncertainty are positively related to more hierarchical IOR modes, while technological uncertainty is negatively related. Li and Li (2010) found that market uncertainty is positively related to the use of flexible ownership strategies in minority/majority JVs. Also, Folta (1998) found that technological uncertainty is positively related to equity-based collaborations versus acquisitions.

Our study is both similar and different from this prior work in the following ways. It is in line with these earlier studies in that it shares the general idea that firms respond differently to different types of uncertainty. In that regard, we complement prior work by specifically considering a high-technology context, in which it also happens to be useful to distinguish between industry technological change and firm-specific technological change (something that has not been considered in earlier studies). At the same time, our study differs from earlier studies in the broader perspective that it adopts, and it therefore makes a major contribution to this literature. What these prior studies have in common in studying IOR, is their focus on *tactical choices*, that is, which governance form to choose in collaborating with a prospective partner. This resonates nicely with the well-studied question in TCE of how to economize on transaction costs in terms of mitigating the hazards of a specific partnership and whether to choose, for example, a more equity-based or a more non-equity-based form of collaboration.

In this study, we go beyond this dominant perspective in the literature and focus instead on the *more strategic decision* of how firms adapt their *entire portfolio* of IORs in response to environmental change. The focus of our study, then, is not on the optimal governance choice for an individual partnership, but rather the corporate-level strategies aimed at accomplishing adaptation to changing environmental conditions. That is why we study the entire range of IOR modes and the diversity at the portfolio level, rather than zeroing in on the choice between only two (or three) modes that has formed the dominant focus until now. As also argued above, our focus on the adaptation of a combination of multiple forms of IORs makes TCE less relevant, given its focus on maximizing efficiency in an individual transaction or partnership rather than on maximizing the joint efficiency of a set of transactions or partnerships.

Because technological change is often ambiguous, the way a firm's executives interpret it plays a considerable role in how that firm responds and thus affects future organizational adaptation (Eggers and Kaplan, 2009). Executives tend to categorize environmental change in terms of opportunities or threats, and these categorizations influence how firms respond to environmental change through different forms of organizational adaptation (Chattopadhyay et al., 2001). The framing of technological change in terms of a threat or an opportunity ties into an emerging stream of literature that examines industry antecedents of risk-taking in organizational actions (e.g., Abrahamson and Rosenkopf, 1993; Chattopadhyay et al., 2001; Mone et al., 1998; Pérez-Nordtvedt et al., 2014). The higher the degree of industry technological change, the higher the degree of unpredictability in new technological developments and the more it may pose a threat to a firm's existing technology position, with attendant losses in future revenues and profit streams. Hence, a firm's executives may perceive industry technology change as carrying a risk of a looming loss for their firm's position. In contrast, firm-specific technological change indicates the extent in which a firm is changing its technologies relative to the rest of the industry. To the extent that it changes its technologies relatively more than the industry as a whole, it pursues a more entrepreneurial strategy, with the potential of creating novel opportunities for commercialization, yielding likely gains in the future (Tushman and Anderson, 1986).

When environmental change is perceived by executives or decision makers in terms of a looming loss or potential gain, earlier studies have relied on prospect theory (Chattopadhyay et al., 2001; Kahneman and Tversky, 1979; Osiyevskyy and Dewald, 2015; Wiseman and Gomez-Mejia, 1998).[4] According to prospect theory, people who anticipate a looming loss become more risk-bearing. As a consequence, they will resort to more externally oriented actions to influence the environment in order to avoid that mounting loss. Meanwhile, people who perceive an opportunity, with its associated potential gain, tend to become more risk-averse, since they have more to lose than they have to gain (Kahneman and Tversky, 1979; Wiseman and Gomez-Mejia, 1998). Following this logic, executives who anticipate a likely loss will resort to more boundary-spanning, externally oriented actions aimed at influencing the environment, while executives who perceive a potential gain bear fewer risks and will resort to fewer boundary-spanning, more internally oriented actions aimed at exploiting or appropriating potential gains. So, executives will take different organizational actions depending on their assessment of whether a technological change is seen as giving rise to a looming loss or a potential gain (Chattopadhyay et al., 2001; Ocasio, 1995; Wiseman and Gomez-Mejia, 1998).

Following the distinction between industry technological change and firm-specific technological change, we will consider how each type of response materializes into adaptations in both the diversity of a firm's IOR portfolio and its corresponding implementation at the level of individual IOR governance modes. Below, we explain how firms respond to industry technological change through an increase in IOR portfolio diversity (Hypothesis 1) and its corresponding implementation at the individual mode level (Hypothesis 2). In a similar vein, we discuss how firms respond to firm-specific change through a decrease in IOR portfolio diversity (Hypothesis 3) and the implementation of that at the individual mode level (Hypothesis 4). Whereas these four hypotheses specify the type of adaptation in response to either form of technological change, they do not address the amount of adaptation to either form. To address this, we also consider the extent to which the degree of adaptation differs when firms respond to either type of change, which leads to our final hypothesis (Hypothesis 5).

[4] In this paper, we prefer to use prospect theory versus threat-rigidity theory. Prospect theory is focused on the loss or gain of tangible resources, rather than the decrease or increase of control over external events (Chattopadhyay et al., 2001; Greve, 1998; Ocasio, 1995). Our focus on changes in technology, that is, industry technological change, pertains to the more tangible resources that technology generally represents, such as knowledge stored in documents, artefacts, and practical applications. This stands in contrast to changes in, for example, government regulation, which are very difficult for individual firms to control. In situations of uncertainty caused by difficult-to-identify threats with high uncontrollability, threat-rigidity is generally considered to be more appropriate (Ocasio, 1995; Staw et al., 1981).

2.3. Industry technological change: increase in IOR portfolio diversity and implementation at the IOR mode level

Industry technological change refers to change at the industry level and indicates the degree of change across a range of technology classes for a group of firms in an industry. In their seminal study, Tushman and Anderson (1986) distinguished between competence-enhancing and competence-destroying technological change. They demonstrated that whereas competence-destroying change obviously has stronger effects on competitive conditions than competence-enhancing change, both types present firms with a stark choice: adapt or face decline. "Both types of technological discontinuities, whether competence-destroying or competence-enhancing, appear to afford a rare opportunity for competitive advantage for firms willing to risk early adoption … those firms that recognize and seize opportunities presented by major advances gain first-mover advantages. Those firms that do not adopt the innovation early … risk failing" (Tushman and Anderson, 1986: 461). The implication is that either type of technological discontinuity only offers a potential gain for the (very) few firms that quickly become first movers. This means that, on average, the vast majority of firms will by definition not be first movers. Consequently, for them, environmental unpredictability is considerably heightened, since either type of technological discontinuity carries a risk of future loss to their existing technology position, with attendant consequences for future revenues and profit streams. So, unless a firm is a first mover, technological change and its associated discontinuities carry, on average, a serious risk of failure (Tushman and Anderson, 1986). Firm executives may therefore perceive industry technology change as carrying a risk of looming loss for their firm.

Some examples of such technological discontinuities include the transition from vinyl records to CDs in music, gasoline engines to hybrid engines in the automotive industry, and the traditional rotary-kiln process to the Edison cement kiln that allowed for the production of much greater volumes of cement for incumbent cement makers (Anderson and Tushman, 1990). This implies that industry technological change is likely to lead to a firm losing its current position if it does not act on it by adapting its strategy and organization, and thus its IOR portfolio. Consistent with prospect theory, this looming loss therefore makes firms become more risk-bearing. As a consequence, they will engage in more boundary-spanning behavior in the form of an increase in external activities, such as IORs, to venture more into the environment as a means of searching for information on new technologies and hedging their bets on future potential, all in an attempt to reduce the risk of a mounting loss. In line with this, it has been shown that with increasing environmental change, firms resort to more adaptive and flexible forms of organizing (e.g., Colombo, 2003; Folta, 1998; Santoro and McGill, 2005).

This implies that firms will engage in more flexible and adaptive IOR modes with lower levels of interdependence, such as licensing agreements, non-equity alliances, and CVC investments. These forms of IORs are considered to be highly flexible and reversible, and therefore less risky, making them more generally effective under the conditions of unpredictability that come with industry technological change. While these more flexible modes do offer less control over the respective partners at the level of the individual relationship, on a portfolio level, their addition offers *more control* by providing opportunities for keeping future options open and thus making firms more adaptive to changing environmental conditions.

However, a reduction in the number of more hierarchical IOR modes cannot generally be accomplished overnight, so that the increase in flexible modes will be stronger than the corresponding decrease in the more integrated forms. As a consequence, we expect that the diversity of a firm's IOR portfolio increases in response to industry technological change. In a similar vein, at the IOR mode level, we expect that firms will initiate more adaptive and flexible linkages to address any potential looming loss that comes with industry technological change, leading primarily to more licensing agreements, followed by non-equity alliances (e.g., research contracts) and corporate venturing activities. Following this logic, they will initiate fewer control-oriented, hierarchical forms of collaboration, with the sharpest decrease being in M&As, followed by JVs and minority investments. Therefore, our first and second hypotheses are:

Hypothesis 1. *The degree of industry technological change is positively related to the diversity of modes used in the focal firms' IOR portfolio.*

Hypothesis 2. *The degree of industry technological change is positively related to the number of new IORs with lower levels of interdependence, such as licensing, non-equity alliances, and CVC investments, and negatively related to the number of new IORs with higher levels of interdependence, such as minority investments, JVs, and M&As.*[5]

2.4. Firm-specific technological change: decrease in IOR portfolio diversity and its implementation at the IOR mode level

Firm-specific technological change indicates the extent in which a firm changes its technologies relative to the rest of the industry. To the extent that a firm changes its technologies more than the industry, it is actively engaging in an entrepreneurial strategy and signaling that it is an early adopter of new products and processes, taking up the learning curve ahead of others (Tushman and Anderson, 1986). It is thereby also able to create more novel opportunities and pursue their early commercialization, yielding likely gains in the future.

Here, prospect theory suggests that likely gains are related to more control-directed actions since firms have more to lose than they do to gain (Chattopadhyay et al., 2001; Kahneman and Tversky, 1979; Osiyevskyy and Dewald, 2015; Wiseman and Gomez-Mejia, 1998). As a consequence, executives perceiving a potential gain in a firm's position will resort to fewer boundary-spanning and more control-oriented actions aimed at exploiting and appropriating the potential gain.

Within the context of IORs, more control-oriented actions imply that firms will rely less on market-like forms of IORs and increase their reliance on more control-oriented, hierarchical forms, such as minority equity investments, JVs, and M&As. These IOR modes are generally more effective in addressing appropriation concerns. In cases where collaboration carries a technology component, especially, concerns of appropriability become more acute (Gulati & Sytch, 1998). In order to mitigate appropriation concerns, the more hierarchical modes of IORs enable greater control, as they offer room for monitoring inputs and free-ridership on the part of a partner, along with dispute resolution procedures in case of misbehavior. Together, M&As, JVs, and, to a lesser extent, minority equity collaboration offer these features in order to govern collaboration based on considerable hierarchical controls (Gulati & Sytch, 1998).

Hence, to appropriate returns from expected gains, a firm will shift its focus away from externally oriented actions aimed at influencing the environment and resort to fewer boundary-spanning and more control-oriented actions. This altered focus towards more control over its collaborations will conflict with high levels of external diversity in its IOR portfolio, which generally consumes a great deal of scarce executive time and attention. Hence, as a response to firm-specific technological

[5] To appreciate the relationship between Hypotheses 1 and 2, bear in mind that overall portfolio diversity can still increase when the increase in IORs with lower levels of interdependence is larger than the decrease in IORs with higher levels of interdependence. In practice, a firm could, for instance, have two non-equity alliances and two JVs, and when industry technological change increases, it might initiate one new non-equity alliance, two extra licensing agreements, and no new JVs (or even terminate a JV). Overall, this results in an increase in diversity at the portfolio level (H1), an increase of IORs with lower levels of interdependence (first part of H2), and a decrease of IORs with higher levels of interdependence (second part of H2).

change, firms will decrease their IOR portfolio diversity to economize on time and attention and allocate those resources to monitoring the more hierarchical forms of collaboration.

This form of adaptation, through a decrease in the IOR portfolio diversity, is further reinforced by the way potential partners are likely to act. A greater degree of firm-specific change implies more uncertainty for potential partners, since the focal firm is taking a different trajectory than the rest of the industry. Following TCE logic here, for a potential partner, this means that it will be faced with two types of risks. The first risk is relational and implies that, to the extent that firm-specific change increases, it will need to adjust contracts, possibly even on an ongoing basis, in order to keep pace with a focal firm's changing trajectories. The second risk is economic and entails a hold-up risk for potential partners, implying that their specific investments to collaborate with the focal firm may not be recoupable and will lose their value as the rest of the industry moves along a different trajectory. So, the more a focal firm heads into a different direction than the rest of the industry, the more difficult it becomes for potential partners to govern the collaboration and assess the value of that focal firm's resources—and the greater the uncertainty of collaboration and its associated transaction costs with the focal firm becomes. As a consequence, with rising transaction costs, a focal firm will come to rely on more integrated modes of collaboration.

In sum, whereas for industry technological change, firms want to keep their options open and hence prefer greater IOR diversity, with firm-specific technological change, firms want to instead exploit and appropriate it and therefore need less diversity. Following prospect theory, this leads to a move away from boundary-spanning activities to more control-oriented modes of collaboration. This is also in line with TCE logic, which argues that with increasing firm-specific uncertainty, potential partners face increasing transaction costs that will lead to more integrated modes of collaboration. This results in the initiation of more control-oriented modes of IORs with higher levels of interdependence, such as minority equity investments, JVs, and M&As, at the expense of modes with lower levels of interdependence, formed by licensing agreements, non-equity alliances (e.g., research agreements), and corporate venturing. Therefore, we expect a decrease in the initiation of new IORs with lower levels of interdependence and an increase in more control-oriented, hierarchical forms of collaboration. Hence, our third and fourth hypotheses are:

Hypothesis 3. *The degree of firm-specific technological change is negatively related to the diversity of the IOR modes used in the focal firms' IOR portfolios.*

Hypothesis 4. *The degree of firm-specific technological change is negatively related to the focal firms' number of new IORs with lower levels of interdependence, such as licensing agreements, non-equity alliances, and CVC investments, and positively related to the number of new IORs with higher levels of interdependence, such as minority investments, JVs, and M&As.*

2.5. Strength of change: industry technological change vs. firm-level change

As argued above, firms' executives tend to categorize environmental change in terms of a looming loss or potential gain, and these categorizations influence how firms respond to environmental change through different forms of organizational adaptation (Chattopadyay et al., 2001). Here, a central idea in prospect theory is that people generally tend to weigh losses more heavily than gains (Tversky and Kahneman, 1992). This resonates with studies examining investments in innovation, which are generally considered risky, and the fact that firms have a strong inclination to imitate others' innovations. In line with the idea of loss aversion, firms will give greater weight to a looming loss of their existing position that puts them at a competitive disadvantage than to an increase of similar magnitude in their position and strengthening of their competitive advantage. This makes them eager to copy others' innovations to avoid incurring losses (Abrahamson and Rosenkopf, 1993).

As argued above, we associate industry technological change with a looming loss, whereas we associate firm-specific change with potential gain. The implication that follows is that, when comparing the strength of firms' adaptive response to either type of change, we expect a firm's response to industry technological change to be stronger than to firm-specific technological change. More specifically, we expect that the effect of an increase in its IOR portfolio diversity (in response to industry technological change) compared to a decrease in its IOR portfolio diversity (in response to firm-specific technological change) will be substantively stronger. In a similar vein, we expect the predicted effects of changes in the individual modes of IOR to be stronger for industry technological change relative to firm-specific change. Therefore, our final hypothesis is:

Hypothesis 5a. *The effect size of industry technological change on a firm's adaptation of its IOR portfolio diversity will be stronger than the effect size of firm-specific technological change.*

Hypothesis 5b. *The effect size of changes in its individual IOR modes (increase or decrease) will be stronger for industry technological change compared to firm-specific change.*

3. Data and methods

3.1. Context and data

The hypotheses were tested on a unique, newly developed, panel database created using the annual rankings of the 100 largest (by number of employees) U.S. public pharmaceutical biotechnology firms. If a firm appeared at least once in the top 100 largest firms, it was included as a focal firm. This resulted in a list of 282 focal firms. These firms were selected for the years 1990–2010 from the Compustat North America database from the following five pharmaceutical biotechnology SIC codes: 2833 (medicinal chemicals and botanical products), 2834 (pharmaceutical preparations), 2835 (in vitro and in vivo diagnostic substances), 2836 (biological products), and 8731 (commercial physical and biological research) (see also Guo et al., 2004; Joos and Zhdanov, 2008).[6]

The pharmaceutical biotechnology industry is particularly useful for studying the relationships between technological change and IOR portfolios (Caner and Bruyaka, 2016). In terms of technological change, it is a high-tech sector and therefore, by definition, subject to a great amount of change. With regard to IORs, this industry is characterized by a rapidly developing and widely dispersed network of scientific leadership (Powell et al., 2005). Additionally, the skills and resources needed to invent new medicines are broadly distributed. These two factors combined have produced a situation in which firms find it necessary to collaborate extensively with one another (see also Deeds and Hill, 1996). Indeed, Van de Vrande et al. (2009) have shown that all the different modes of IORs are represented in this industry.

Moreover, the industry plays an important role in shaping the social and economic environment. As such, the media reports frequently on

[6] Although the initial selection of the 100 largest firms in any given year might lead to a specific subset of large firms, the final 282 focal firms have a relatively large standard deviation in terms of their firm size, indicating a more diverse sample. Furthermore, smaller firms that had any IORs with these focal firms are incorporated in the analyses. Moreover, focusing on the largest firms has two advantages: first, it enables us to have a consistent set of firms over time; and second, as opposed to small or privately held firms, large firms must maintain and disclose their IORs and other relevant information. For this reason, earlier IOR research has also focused on the largest firms (e.g., Ahuja, 2000a; Beckman et al., 2004; Hitt et al., 1996; Keil et al., 2008).

developments in it and IORs among the firms. This in turn results in a high availability of the recorded data needed to investigate our hypotheses. Finally, “biotechnology techniques have applications in a number of subfields, including therapeutic pharmaceuticals, diagnostic pharmaceuticals, agriculture, and chemicals. In this sense, the biotechnology industry can be seen as an alternative to a multi-industry study” (Folta, 1998 Equation can be dealt with Citation."/ > , p. 1015).

The 282 largest focal firms from the Compustat North America database were connected to other secondary databases. Information on their IORs was gathered from multiple secondary data sources and matched, including two Securities Data Corporation (SDC) platinum databases from Thomson (i.e., the Alliances and Joint Ventures database and the M&A database) and Thomson’s VentureXpert. Patent information, which was used to measure technological change, was obtained from the USPTO and the NBER.

3.2. Measures

3.2.1. Dependent variables: IOR portfolio diversity and the number of individual IOR modes

To operationalize the IORs of the focal firms, the 282 focal firms from Compustat were matched to other databases through extensive name standardization, name matching, and matching of other firm identifiers (e.g., CUSIP, GVKEY). This matching was performed twice (by two researchers independently) and a few minor differences were resolved. CVC investments were pooled from Thomson’s VentureXpert, which combines data from industry associations like the National Venture Capital Association and the investment banking community. VentureXpert has been used frequently in prior research (e.g., Dushnitsky and Lavie, 2010; Dushnitsky and Lenox, 2005a; Dushnitsky and Lenox (2005b); Mann and Sager, 2007; Ozmel et al., 2013; Van de Vrande et al., 2009).

Data on the licensing agreements, non-equity alliances, minority investments, JVs, and M&As of the 282 focal firms were pooled from two well-known and frequently used Securities Data Corporation (SDC) platinum databases from Thomson (used by e.g., Anand and Khanna, 2000; Bergh and Lim, 2008; Garcia Canal et al., 2008; Hagedoorn and Cloodt, 2003; Phelps, 2010; Sahaym et al., 2007; Sampson, 2007; Schilling and Phelps, 2007; Srivastava and Gnyawali, 2011). These databases are among the most comprehensive sources of information on IORs and are two of the only sources available for large-scale empirical studies in this field (see Anand and Khanna, 2000).

The data stored in the SDC databases have been obtained from Securities and Exchange Commission (SEC) filings and those of their international counterparts, trade publications, news sources and wires, company annual reports, and other sources. Although the two SDC databases are the most comprehensive and frequently used databases, two limitations apply. First, SDC data is quite sparse up until 1990 (Anand and Khanna, 2000; Schilling, 2009). We therefore started our analysis period in 1990. Second, a manual check of a subset of the SDC data indicated that not all IORs could be double-checked and verified. Therefore, all of the IORs for which the announcement date was estimated, rather than known, were removed from the data, since these may never have materialized (in line with e.g., Sampson, 2007).

Based on the two SDC databases and Thomson’s VentureXpert, the *number of individual IOR modes* was created as the sum of each IOR mode initiated, per focal firm, for a given year. *IOR portfolio diversity* (i.e., the diversity of all the IORs of a focal firm) was operationalized using the Herfindahl-Hirschman Index (HHI, i.e., the sum of the squared share of the number of IORs per IOR mode), also known as Blau’s index of heterogeneity. This measure is a very commonly used measure for diversity as variety (Harrison and Klein, 2007) and has therefore been frequently used in previous studies (e.g., Duysters and Lokshin, 2011; Van de Vrande, 2013). IOR portfolio diversity is operationalized as 1-HHI, since the HHI is a concentration measure, and we prefer having the values that are near one correspond to high levels of diversity, whereas values near zero should represent low levels. When a focal firm, for example, has two non-equity alliances and two JVs, the portfolio diversity would be: $[1-(2/4)^2+(2/4)^2] = 0.50$. If a focal firm has three non-equity alliances, two licensing agreements, and two JVs, the IOR portfolio diversity would be: $[1-(3/7)^2+(2/7)^2+(2/7)^2] = 0.65$.

Independent Variable: Technological Change. Technological change refers to change over time and was operationalized based on U.S. patent information from the 282 focal firms. U.S. patents in the pharmaceutical biotechnology industry can be regarded as a reliable source of information, since this is an industry with strong patent protection, making the propensity to patent high (Deeds and Hill, 1996). In line with prior studies (e.g., Dushnitsky and Lenox, 2005a; Dushnitsky and Lenox (2005b); Hagedoorn and Cloodt, 2003; Ozmel et al., 2013), information from the U.S. Patent and Trademark Office (USPTO) was used to complement the data from the 282 focal firms. Because the USPTO grants patents to both the parent firm and to the firm’s subsidiaries (Patel and Pavitt, 1997), the patent data needed to be consolidated at the parent firm level.

The NBER (2008) matching database between Compustat and the USPTO was used to retrieve and consolidate the patents assigned to the focal firms (Hall et al., 2001). Because the delay between the patent application date and the patent grant date can be up to several years on average, the NBER data up to and including 2006 were used. The application date was used to assign the patents to the specific years, since it most closely relates to the time of the technological change. The NBER information also enabled the reallocation of patents over time, reflecting M&As between the focal firms.

Year-to-year changes in the distribution of the patents across the patent classifications were used to operationalize technological change (based on e.g., Jaffe, 1968; Kang and Marhold, 2016; Sampson, 2007; Van de Vrande et al., 2009)[7]. In the first step, a vector was generated for each firm’s technological portfolio by measuring the distribution of its patents across the patent classes, year by year. In a second step, the similarities of these vectors in two subsequent years were measured by the Pearson correlation coefficient ρ. Since similarity is the opposite of change, technological change was then calculated as $1 - \rho$, so that higher values indicate higher levels of technological change. This operationalization is in line with previous studies (e.g., Kang and Marhold, 2016; Van de Vrande et al., 2009). In a recent comparison across alternative operationalizations, Kang and Marhold (2016) furthermore showed that there is a high degree of overlap between these alternative operationalizations (e.g., Gilsing, Vanhaverbeke, and Pieters (2014), who used the relative difference between the patents of the last three years and the current year, and Goerzen (2007), who used the percentage of change in the patents between two years).[8]

The technological change operationalization thus captures the fluctuations of patenting behavior in the patent classes over time. If there is limited fluctuation in the patenting behavior, technological change is considered to be low. *Industry technological change*, which is defined as the degree of change associated with technologies for a group of firms in an industry, was measured based on patents for all 282 focal firms in a given year. *Firm-specific technological* change, which is

[7] Both Jaffe (1986) and Sampson (2007) compare the diversity of the distribution of the patents over the patent classes between multiple firms, while in this paper the focus is on comparing the diversity of the distribution of the patents over the patent classes across time, both for all firms in the industry combined (industry technological change), as well as for the individual firms (firm-specific technological change).

[8] The patent data distinguishes between three hierarchical levels of technology classes (similar to the two-digit, three-digit, or four-digit SIC codes). To enable sufficient variation (not the case at the highest level) but prevent minor changes in related technology classes (the case at the lowest level), the patent subclass level (the middle level) is used (also referred to as the three-digit level).

defined as the degree of change associated with technologies used by one specific firm, was measured in two steps. In the first step, the firm-level change was calculated per individual focal firm in a given year based on the patents in technology classes of each firm. In a second step, the industry technological change was subtracted from the firm-level change, to yield the firm-specific change. This operationalization of firm-specific technological change captures the change at the firm level and is relative to the industry technological change.

For a technological domain or industry, some patent classes are more central and important than others (e.g., Kang and Marhold, 2016; Van de Vrande et al., 2009). Previous studies have therefore incorporated this importance into their operationalizations of technological change. Kang and Marhold (2016) and Van de Vrande et al. (2009), for example, used the 80% most frequent patented technology classes. To prevent the exclusion of less prominent technology classes (i.e., the other 20%), our technological change operationalization extends these previous operationalizations by calculating a weight for each patent class. This weight was calculated as the share of the total number of patents in that patent class, based on all the focal firms, over the total time period. For each year, this weight per patent class was multiplied by the number of patents in that patent class.

Control Variables. To minimize alternative explanations, the analyses also include a number of relevant control variables. First of all, we control for the *number of marketing alliances*, as a proxy for specialized complementary assets, by taking the sum of the number of marketing alliances initiated in the five years (t-1 thru t-5) before the period of analysis. The operationalization is inspired by Arora and Nandkumar (2012), who measured complementary assets by the number of sales/marketing executives. Second, we controlled for the stage of development (in line with e.g., Ceccagnoli and Hicks, 2013), by taking the sum of the number of *citations to recent patents* (i.e., the application year of the cited patent falls within three years before the citing patent application year). Third, the effectiveness of patent protection is controlled for by taking the number of *citations the focal firms' patents have to scientific knowledge* (in line with e.g., Ceccagnoli and Hicks, 2013). The patent citation data were obtained from the USPTO. Fourth, we controlled for *firm size*, which can influence the focal firm's propensity to engage in IORs. Firm size was operationalized as the number of employees per year. Fifth, it is important to control for *R&D intensity*, measured by the focal firm's total R&D expenditure per year (this information was directly obtained from the Compustat database), because it increases a focal firm's capacity to recognize, value, and work with external resources and knowledge through IORs.

Sixth, the focal firm's past *experience with each IOR mode* can lead to a build-up of specific capabilities and preferences per IOR mode. IOR experience was therefore controlled for and operationalized as the sum of the number of IORs initiated per mode in the five years before the period of analysis. Seventh, since the pharmaceutical biotechnology industry could be considered a multi-industry (Folta, 1998), and different industries have different propensities to patent, the focal firm's *primary SIC industry* dummy code is controlled for.[9]

3.3. Methods

To investigate the relationships between technological change (both industry and firm-specific) and the diversity in the IOR portfolio, a random effects OLS panel data estimation was used. To investigate the relationships between technological change (both industry and firm-specific) and the counts of the individual IOR modes, random effects negative binomial panel data estimations were used. Random effects estimation was chosen because it has a number of advantages over fixed effects in our empirical context. First, it retains time-invariant variables like the industry dummy control variables. Second, it includes the observations of firms that did not initiate a specific IOR mode (e.g., if a firm did not initiate any non-equity alliance, it would be dropped from the non-equity alliance analyses if fixed effects estimation were used; fixed effects estimations would therefore result in different samples being compared across the models). Third, random effects estimation does not suffer from the incidental parameter problem that fixed effects estimation has (i.e., the coefficients of dummy variables used in fixed effects estimations are not consistent, since the number of these parameters increases as the number of observational units increases, and in these analyses, there are 282 observational units). Fourth, random effects estimation allows for individual effects and thereby controls for unobserved heterogeneity. A Hausman test (based on Model 7) ruled out the need for fixed effects ($p = 0.453$). To check for robustness, the negative binomial models were also re-analyzed with Poisson estimations. The results are presented in Table 4. The results show consistent findings compared to the findings presented in Table 3.

4. Results

The descriptive statistics and pairwise correlations can be found in Table 1. Industry technological change has a mean of 0.14, while the mean of firm-specific technological change is 0.68. At -0.17, the correlation between these two measures is low. The correlations between the variables do not suggest that collinearity is an issue. The diversity of modes in an IOR portfolio has a mean of 0.14, indicating relatively low levels of IOR portfolio diversity. The number of separate IOR modes used by the 282 focal firms is presented in Table 2. In total, the firms initiated 8440 new IORs.

Table 3 presents the results of the analyses of the impact of both industry and firm-specific technological change on the diversity of IOR modes in a portfolio (Model 1) and the initiation of new individual IOR modes (Models 2–7). Industry and firm-specific technological change are simultaneously included in the analyses to control for their impact on each other.

The results of Model 1 (Table 3) indicate a positive and significant relationship between industry technological change and the diversity of IOR modes in a portfolio ($\beta = 0.09$, $p < 0.01$), confirming Hypothesis 1. Models 2 and 3 show a positive and significant relationship between industry technological change and both licensing agreements ($\beta = 0.89$, $p < 0.001$) and non-equity alliances ($\beta = 1.46$, $p < 0.001$). Model 4, however, reveals a significant negative relationship between industry technological change and CVC investments ($\beta = -2.87$, $p < 0.001$). Therefore, the first part of Hypothesis 2, which argued that industry technological change would be positively related to the focal firms' newly initiated IORs with lower levels of interdependence (i.e., licensing, non-equity alliances, and CVC investments), is only partly confirmed.

Models 5 and 7 show a negative and significant relationship between industry technological change and both minority investments ($\beta = -1.06$, $p = 0.054$) and M&As ($\beta = -0.82$, $p < 0.01$). Model 6, however, reveals a non-significant relationship between industry technological change and JVs. Therefore, the second part of Hypothesis 2, arguing for a negative relationship between industry technological change and newly initiated IORs with higher levels of interdependence (i.e., minority investments, JVs, and M&As), is also partly confirmed. Overall, Hypothesis 2 is thus partly confirmed.

Model 1 of Table 3 also shows a significant negative relationship between firm-specific technological change and the diversity of IOR modes used in a portfolio ($\beta = -0.03$, $p < 0.01$), thereby confirming Hypothesis 3. The first part of Hypothesis 4, which argued for a negative relationship between firm-specific technological change and the focal firms' initiation of new IORs with lower levels of interdependence—licensing agreements ($\beta = -0.17$, $p = 0.051$), non-equity

[9] Controlling for the years (through the incorporation of year dummies) raised further issues due to the correlation between industry technological change (per year) and the year dummy variables. These year dummy variables were therefore excluded from the analyses.

Table 1
Descriptive Statistics and Correlations.

Variable	Mean	Std. Dev.	Min.	Max.
1. Industry Tech. Change	0.14	0.13	0.00	0.40
2. Firm-specific Tech. Change	0.68	0.49	−0.40	2.00
3. IOR Portfolio Mode Diversity	0.14	0.25	0.00	0.81
4. Licensing Agreements	0.52	1.26	0.00	11.00
5. Non-equity Alliances	0.61	1.41	0.00	11.00
6. CVC Investments	0.28	1.89	0.00	27.00
7. Minority Investments	0.11	0.46	0.00	6.00
8. Joint Ventures (JVs)	0.17	0.89	0.00	23.00
9. Mergers & Acquisitions (M&As)	0.56	1.23	0.00	14.00
10. Marketing Alliances	0.16	0.53	0.00	4.00
11. Citing Recent Patents	0.56	2.32	0.00	61.00
12. Citing Scientific Sources	10.41	31.45	0.00	383.00
13. Firm Size[a]	6.55	17.46	0.00	122.20
14. Firm R&D Intensity[b]	0.25	0.80	0.00	12.18
15. Licensing Experience	0.35	1.05	0.00	8.00
16. Non-equity Alliance Experience	0.09	0.41	0.00	4.00
17. CVC Investments Experience	0.27	1.49	0.00	19.00
18. Minority Investments Experience	0.10	0.43	0.00	5.00
19. JV Experience	0.17	0.50	0.00	3.00
20. M&A Experience	0.53	1.61	0.00	17.00

Descriptive Statistics and Correlations.

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1. Industry Tech. Change	1																			
2. Firm-specific Tech. Change	−0.17	1																		
3. IOR Portfolio Mode Diversity	0.05	−0.30	1																	
4. Licensing Agreements	0.07	−0.29	0.59	1																
5. Non-equity Alliances	0.11	−0.30	0.60	0.57	1															
6. CVC Investments	−0.04	−0.11	0.20	0.15	0.19	1														
7. Minority Investments	−0.03	−0.18	0.46	0.40	0.37	0.20	1													
8. Joint Ventures (JVs)	0.03	−0.15	0.37	0.37	0.41	0.04	0.37	1												
9. Mergers & Acquisitions (M&As)	−0.05	−0.13	0.49	0.32	0.39	0.27	0.38	0.35	1											
10. Marketing Alliances	0.04	−0.25	0.26	0.32	0.28	0.03	0.14	0.06	0.11	1										
11. Citing Recent Patents	−0.04	−0.04	0.04	0.04	0.03	−0.01	0.01	0.02	0.00	0.02	1									
12. Citing Scientific Sources	−0.08	−0.43	0.40	0.42	0.36	0.12	0.27	0.25	0.20	0.38	0.04	1								
13. Firm Size[a]	−0.02	−0.35	0.51	0.51	0.60	0.39	0.38	0.30	0.46	0.33	0.01	0.57	1							
14. Firm R&D Intensity[b]	−0.05	−0.28	0.42	0.38	0.45	0.37	0.28	0.14	0.36	0.34	0.00	0.46	0.84	1						
15. Licensing Experience	0.05	−0.32	0.34	0.38	0.38	0.10	0.19	0.13	0.17	0.84	0.02	0.50	0.46	0.42	1					
16. Non-equity Alliance Experience	0.03	−0.14	0.14	0.10	0.12	0.05	0.08	0.03	0.10	0.11	0.02	0.12	0.13	0.08	0.10	1				
17. CVC Investments Experience	0.02	−0.21	0.28	0.30	0.33	0.42	0.21	0.10	0.19	0.29	0.03	0.39	0.46	0.31	0.35	0.00	1			
18. Minority Investments Experience	0.04	−0.19	0.30	0.26	0.32	0.27	0.23	0.17	0.18	0.23	0.02	0.37	0.38	0.21	0.42	0.14	0.67	1		
19. JV Experience	0.06	−0.30	0.32	0.33	0.39	0.19	0.16	0.18	0.19	0.48	0.02	0.46	0.48	0.38	0.65	0.06	0.52	0.55	1	
20. M&A Experience	0.04	−0.28	0.37	0.36	0.42	0.20	0.23	0.28	0.29	0.51	0.01	0.49	0.51	0.39	0.62	0.14	0.48	0.56	0.53	1

[a] Divided by 10^3; b Divided by 10^6.

Table 2
Number of Separately Initiated IOR Modes.

IOR Modes	#
Licensing Agreements	1,736
Non-equity Alliances	2,150
CVC Investments	1,290
Minority Investments	404
Joint Ventures (JVs)	600
Mergers & Acquisitions (M&As)	2,260
Total	8,440

alliances (β = -0.19, $p < 0.05$), and CVC investments (β = -0.87, $p < 0.001$)—is confirmed based on Models 2-4.

Models 5 and 6 reveal a significant negative relationship between firm-specific technological change and both the initiation of new minority investments (β = -0.75, $p < 0.001$) and JVs (β = -0.38, $p < 0.05$), while Model 7 reveals a negative, but non-significant, relationship with the initiation of new M&As (β = -0.13, n.s.). Combined, these last three models show a negative relationship between firm-specific technological change and the initiation of new IORs with relatively higher levels of interdependence, with the exception of M&As, which conflicts with the second part of Hypothesis 4, in which we argued for a positive effect. Overall, Hypothesis 4 is thus partly confirmed.

With regard to Hypothesis 5a and the impact on the diversity in the IOR portfolio, Model 1 in Table 3 shows that the coefficient of industry technological change (β = 0.09, std. err.: 0.03) is larger than the coefficient of firm-specific technological change (β = -0.03, std. err.: 0.01). Testing the differences between these coefficients reveals a significant difference ($p < 0.001$), thereby confirming Hypothesis 5a. With regard to Hypothesis 5b and the impact on the number of IOR modes, Models 2 through 7 in Table 3 reveal larger coefficients of industry technological change for all IOR modes except CVC investments. Testing the differences between these coefficients reveals a significant difference for licensing agreements ($p < 0.001$), non-equity alliances ($p < 0.001$), CVC investments ($p < 0.001$), JVs ($p = 0.07$), and M&As ($p < 0.01$). So, with the exception of minority investments, Hypothesis 5b is also confirmed.

In contrast to our predictions (second part of H4), increasing levels of firm-specific technological change result in a decrease in almost all IOR modes. To investigate this in more detail, an additional comparison was made for the overall portfolio diversity, in addition to all the individual IOR modes, with regard to firms experiencing above and below the mean levels of technological change (both industry as well as firm-specific changes). To provide additional insight, the total number of

Table 3
Industry and Firm-specific Technological Change and IORs.

Random Effects **negative binomial** Variables	Model 1 IOR Portfolio Diversity	Model 2 New Licensing Agreements	Model 3 New Non-equity Alliances	Model 4 New CVC Investments	Model 5 New Minority Investments	Model 6 New JVs	Model 7 New M&As
Industry Tech. Change	0.09**	0.89***	1.46***	−2.87***	−1.06†	0.47	−0.82**
	(0.03)	(0.26)	(0.23)	(0.61)	(0.55)	(0.48)	(0.26)
Firm-specific Tech. Change	−0.03**	−0.17†	−0.19*	−0.87***	−0.75***	−0.38*	−0.13
	(0.01)	(0.09)	(0.08)	(0.23)	(0.19)	(0.17)	(0.08)
Marketing Alliances	0.02	−0.03	0.00	0.03	0.40	−0.30	0.10
	(0.03)	(0.24)	(0.24)	(0.50)	(0.32)	(0.44)	(0.29)
Citing Recent Patents	0.00	0.01	0.01	−0.01	0.01	0.02	0.01
	(0.00)	(0.01)	(0.01)	(0.05)	(0.03)	(0.02)	(0.01)
Citing Scientific Sources	0.00**	0.00	−0.00**	−0.01***	0.00	0.00***	−0.00†
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Firm Size	0.00***	0.01*	0.02***	0.02**	0.03***	0.02***	0.02***
	(0.00)	(0.00)	(0.00)	(0.01)	(0.01)	(0.01)	(0.00)
Firm R&D Intensity	−0.00	−0.14*	−0.19***	0.18**	−0.19*	−0.66***	0.00
	(0.01)	(0.05)	(0.04)	(0.06)	(0.08)	(0.12)	(0.04)
Licensing Exp.	0.00	0.18	0.19	0.67†	−0.16	0.37	−0.11
	(0.02)	(0.15)	(0.15)	(0.36)	(0.19)	(0.25)	(0.17)
Non-equity Alliance Exp.	0.02	0.35*	0.37*	−0.10	0.14	−0.08	−0.04
	(0.02)	(0.18)	(0.16)	(0.21)	(0.20)	(0.30)	(0.17)
CVC Investments Exp.	−0.01	0.07	0.02	0.21*	−0.10	0.07	−0.02
	(0.01)	(0.06)	(0.06)	(0.09)	(0.07)	(0.10)	(0.08)
Minority Investments Exp.	0.05t	−0.16	0.03	−0.27	0.62*	0.14	0.20
	(0.03)	(0.24)	(0.24)	(0.38)	(0.27)	(0.43)	(0.27)
JV Exp.	0.01	0.02	0.30†	−1.06*	−0.02	0.22	0.19
	(0.02)	(0.19)	(0.18)	(0.45)	(0.24)	(0.27)	(0.17)
M&A Exp.	0.01†	0.05	0.02	0.03	0.05	−0.05	0.09
	(0.01)	(0.06)	(0.06)	(0.12)	(0.07)	(0.07)	(0.08)
SIC 2833	0.00	1.75**	−0.46	1.65	−23.82	0.31	0.32
	(0.04)	(0.66)	(0.53)	(1.69)	(5.36)	(0.84)	(0.46)
SIC 2834	0.03	2.12***	0.42	−0.67	0.12	1.04*	−0.14
	(0.02)	(0.47)	(0.27)	(0.91)	(0.41)	(0.50)	(0.24)
SIC 2835	0.00	2.01***	0.15	−2.79*	−0.23	0.19	−0.10
	(0.03)	(0.50)	(0.30)	(1.10)	(0.47)	(0.57)	(0.28)
SIC 2836	0.04	2.35***	0.49†	0.14	0.01	0.17	−0.22
	(0.03)	(0.49)	(0.29)	(0.89)	(0.44)	(0.56)	(0.27)
Constant	0.07**	−2.16***	−0.28	−0.12	−0.85†	−1.49**	0.66*
	(0.02)	(0.48)	(0.29)	(0.88)	(0.49)	(0.54)	(0.26)
Observations	2,994	2,994	2,994	2,994	2,994	2,994	2,994
Number of firms	278	278	278	278	278	278	278
Sigma_u	0.0859	.	.	.	.	.	.
Sigma_e	0.186	.	.	.	.	.	.
Rho	0.176	.	.	.	.	.	.
Log-likelihood [a]	.	−2274	−2490	−658.5	−817.5	−992.2	−2536

IORs (i.e., the count of the number of IORs per year) and the number of partners (i.e., the count of the unique number of partners in the portfolio across all IOR modes) were also included in this comparison.

Table 5 shows the means and standard deviations for these variables. The first two columns present the overall sample, followed by the values above and below the average industry technological change. The last four columns show the values above and below the average firm-specific technological change. The results confirm the results in Table 3 by showing that firms experiencing above-average firm-specific technological change have a lower IOR portfolio diversity and fewer individual IOR modes than firms experiencing below-average firm-specific technological change, as well as compared to the overall sample. Also, the total number of IORs and the number of partners are lower in these comparisons. This is in contrast to the means for firms experiencing below-average firm-specific technological change, which have a higher portfolio diversity, more individual IOR modes, more IORs in total, and more partners. The split sample analyses based on industry technological change show smaller differences.

5. Discussion and conclusions

The literature on organizational adaptation suggests that firms need to adapt to changing environmental conditions (e.g., Haveman, 2003; Hrebiniak and Joyce, 1985; Meyer et al., 1990; O'Reilly and Tushman, 2008; Siggelkow and Levinthal, 2003). The implication for IORs is that to secure future value creation and value capture from collaboration, firms need to also adapt their external organization of collaborations and partnerships (Ahuja et al., 2012; Phelps et al., 2012; Powell et al., 2005; Kantola et al., 2017). This raises a question that has not been considered until now, either in the literature on organizational adaptation or in the literature on interfirm relationships: how firms adapt their external organization and address such change is important for understanding how they accomplish the major strategic task of responding to environmental circumstances.

In this study, we considered the role of technological change as an antecedent of adaptations to IORs. To address this issue, we distinguished between two types of technological change, namely industry and firm-specific. The key questions we considered were: to what extent do firms respond differently to each of these forms of change; and do they do it by exerting more control or becoming more adaptive? To study this, we considered both *what* type of responses firms exhibit, through either an increase or decrease in their IOR portfolio diversity (portfolio level), and also *how*, specifically, they put these adaptations into action (mode level).

Following on our theoretical framework and empirical findings, a number of results stand out. First, regarding industry level change, we

Table 4
Industry and Firm-specific Technological Change and IORs.

Poisson Regression Variables	Model 1 IOR Portfolio Diversity	Model 2 New Licensing Agreements	Model 3 New Non-equity Alliances	Model 4 New CVC Investments	Model 5 New Minority Investments	Model 6 New JVs	Model 7 New M&As
Industry Tech. Change	0.09**	1.04***	1.53***	−2.96***	−1.21*	0.60	−1.04***
	(0.03)	(0.20)	(0.19)	(0.33)	(0.48)	(0.37)	(0.21)
Firm-specific Tech. Change	−0.03**	−0.51***	−0.47***	−0.91***	−0.78***	−0.62***	−0.06
	(0.01)	(0.06)	(0.06)	(0.10)	(0.15)	(0.12)	(0.06)
Marketing Alliances	0.02	0.34***	0.19**	−1.45***	0.22	−0.15	−0.00
	(0.03)	(0.06)	(0.06)	(0.14)	(0.17)	(0.13)	(0.08)
Citing Recent Patents	0.00	0.02**	0.02**	−0.11**	−0.02	0.03*	0.00
	(0.00)	(0.01)	(0.01)	(0.04)	(0.04)	(0.01)	(0.01)
Citing Scientific Sources	0.00**	0.00***	−0.00	−0.00***	0.00	0.00***	−0.00***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Firm Size	0.00***	0.03***	0.03***	0.03***	0.04***	0.04***	0.03***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Firm R&D Intensity	−0.00	−0.20***	−0.14***	0.21***	−0.18**	−0.68***	−0.13***
	(0.01)	(0.03)	(0.03)	(0.03)	(0.06)	(0.08)	(0.03)
Licensing Exp.	0.00	−0.08*	−0.08*	0.38***	−0.04	−0.09	−0.05
	(0.02)	(0.04)	(0.04)	(0.08)	(0.10)	(0.08)	(0.05)
Non-equity Alliance Exp.	0.02	0.07†	0.09*	−0.17***	−0.10	−0.28**	0.10*
	(0.02)	(0.04)	(0.03)	(0.05)	(0.08)	(0.09)	(0.04)
CVC Investments Exp.	−0.01	−0.02*	−0.06***	0.26***	−0.07*	−0.12***	−0.06***
	(0.01)	(0.01)	(0.01)	(0.03)	(0.03)	(0.02)	(0.01)
Minority Investments Exp.	0.05†	0.01	0.11*	0.51***	0.72***	0.11	0.13†
	(0.03)	(0.06)	(0.05)	(0.07)	(0.13)	(0.11)	(0.07)
JV Exp.	0.01	0.10†	0.19***	−1.88***	−0.57***	0.08	0.03
	(0.02)	(0.05)	(0.05)	(0.16)	(0.15)	(0.11)	(0.06)
M&A Exp.	0.01†	0.01	0.05***	0.23***	0.01	0.13***	0.09***
	(0.01)	(0.01)	(0.01)	(0.03)	(0.03)	(0.02)	(0.01)
SIC 2833	0.00	1.53***	−0.51	0.06	−15.32	0.75	−0.39*
	(0.04)	(0.45)	(0.35)	(0.68)	(9.06)	(0.54)	(0.18)
SIC 2834	0.03	2.15***	0.48**	0.80*	0.36	1.11**	−0.58***
	(0.02)	(0.36)	(0.15)	(0.37)	(0.35)	(0.36)	(0.09)
SIC 2835	0.00	1.87***	0.23	−0.04	−0.00	0.20	−0.72***
	(0.03)	(0.36)	(0.17)	(0.43)	(0.40)	(0.41)	(0.11)
SIC 2836	0.04	2.21***	0.49**	1.62***	0.52	0.48	−0.64***
	(0.03)	(0.36)	(0.16)	(0.37)	(0.37)	(0.39)	(0.10)
Constant	0.07**	−3.08***	−1.42***	−2.33***	−2.50***	−2.98***	−0.24*
	(0.02)	(0.36)	(0.16)	(0.37)	(0.36)	(0.37)	(0.10)
Observations	2,994	2,994	2,994	2,994	2,994	2,994	2,994
Number of firms	278	278	278	278	278	278	278
Sigma_u	0.0859	.	.	.	.	.	.
Sigma_e	0.186	.	.	.	.	.	.
Rho	0.176	.	.	.	.	.	.
Log likelihood [a]	.	−2651	−2821	−1597	−886.5	−1235	−2981

Standard errors in parentheses. *** $p < 0.001$, ** $p < 0.001$, * $p < 0.05$, † $p < 0.10$.
[a] Models 2–7 were run as separate models for the different IOR modes. Therefore, no comparison can be made between the log likelihoods.

found strong empirical evidence for Hypothesis 1, which specifies a positive relationship between industry technological change and IOR portfolio diversity (at the portfolio level). Second, at the mode level, we found both a confirmation as well as a rejection of Hypothesis 2, which specifies how firms put adaptations to their IOR portfolio diversity into action. We found confirmation in so far as licensing and non-equity alliances were concerned. This is in line with our argument that when faced with a looming loss emanating from industry technological change, firms will engage in more market-like, flexible forms of collaboration. We also found some confirmation for our prediction of a negative relationship between the degree of industry technological change and the number of newly initiated IORs with higher levels of interdependence. Meanwhile, while we found the predicted negative effect for M&As and minority investments, the effect for JVs was non-

Table 5
Comparison Above and Below Industry and Firm-specific Technological Change.

	Overall Sample		Above Industry Average		Below Industry Average		Above Firm-specific Average		Below Firm-specific Average	
Variable	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
IOR Portfolio Mode Diversity	0.14	0.25	0.16	0.26	0.13	0.24	0.09	0.20	0.22	0.29
Licensing Agreements	0.52	1.26	0.61	1.38	0.45	1.15	0.27	0.76	0.90	1.71
Non-equity Alliances	0.61	1.41	0.77	1.62	0.48	1.19	0.32	0.90	1.06	1.86
CVC Investments	0.28	1.89	0.20	1.49	0.33	2.15	0.13	1.28	0.50	2.54
Minority Investments	0.11	0.46	0.09	0.38	0.12	0.51	0.05	0.32	0.19	0.60
Joint Ventures (JVs)	0.17	0.89	0.22	1.09	0.13	0.68	0.07	0.41	0.33	1.30
Mergers & Acquisitions (M&As)	0.56	1.23	0.49	1.10	0.62	1.32	0.46	1.10	0.71	1.38
Number of IORs	2.24	4.67	2.38	4.68	2.13	4.66	1.30	2.86	3.69	6.26
Number of Partners	1.68	3.46	1.87	3.86	1.53	3.09	1.02	1.83	2.70	4.85

significant.

This is also consistent with a number of other studies such as those by Santoro and McGill (2005), who found that technological uncertainty decreased the likelihood of hierarchical governance; Cuypers and Martin (2010), who found that economic, local institutional and exchange rate uncertainty led to a smaller share of ownership in foreign JVs; and Li and Li (2010), who found that market uncertainty was positively related to the use of flexible ownership strategies in minority/majority JVs. Also, Folta (1998) found that technological uncertainty was positively related to equity-based collaborations versus acquisitions.

However, in contrast to these studies, as well as to our own Hypothesis 2, a negative relationship was found between industry technological change and CVC investments, considered a flexible mode based on its level of interdependence, whereas a positive effect had been predicted. This negative effect stands in sharp contrast with the positive effect for licensing and non-equity alliances, as the other two flexible modes of IORs. Our interpretation of this unexpected finding is as follows. Our study differs from earlier studies in its focus on the portfolio level, which is revealing because it shows how firms choose to adapt through a very rigorous adjustment of their entire IOR portfolio. The strong emphasis on the addition of the two most flexible forms of collaboration, at the expense of control-oriented forms and even also of CVCs, suggests that firms adapt to industry technological change through a major overhaul of their IOR portfolio. Although this still fits with the underlying logic of our predictions (cf. Hypotheses 1 and 2), this is an even stronger and more directed response than we anticipated. In fact, this appears to be a major adaptation process of portfolio churning, in which firms relinquish control at the level of individual partners but gain control at the portfolio level by creating the possibility for keeping future options open and, in this way, become more adaptive to changing environmental conditions.

Regarding firm-specific change, we found strong empirical evidence for Hypothesis 3, which specifies a negative relationship with IOR portfolio diversity. At the mode level, we found both a confirmation as well as a rejection of Hypothesis 4, which specifies how firms put changes to their IOR portfolio diversity into action. We found confirmation for the first part of Hypothesis 4, predicting a negative relationship between firm-specific technological change and a focal firm's initiation of new IORs with low levels of interdependence, comprised of CVC investments, non-equity alliances, and licensing. In contrast to the second part of Hypothesis 4, however, a significant negative effect was found for both minority investments and JVs, whereas a negative non-significant effect was found for M&As. This runs counter to our prediction.

Because of our focus on the entire portfolio level and the additional comparison in Table 5, we can observe that firms decreased the initiation of new IORs across all modes except for M&As. This implies that firms respond to firm-specific change by cutting back on five out of six IOR modes, including both flexible and more hierarchical modes. Earlier, we argued that the prospect of gain leads to fewer boundary-spanning and more control-oriented forms of collaboration (i.e., more hierarchical). What we had not predicted though, which is what these findings show, was that firms make the more fundamental decision to adapt by decreasing their collaboration activities across most of their IOR modes, flexible as well as hierarchical forms. This suggests that firms prefer to gain control through less emphasis on external collaboration overall, indicating that they favor a stronger in-house orientation in view of appropriating the expected gain.

Furthermore, an additional explanation for why focal firms' intensify their in-house orientation may be found by taking the perspective of potential partners into account. Following Ahuja (2000b), the likelihood of collaboration with a focal firm depends on not only its own inducements to collaborate, but also its attractiveness as a partner and the value of the resources it has to offer potential partners; that is, "it takes two to tango." However, when a focal firm starts taking a different direction than the rest of the industry, it becomes more difficult for potential partners to govern the collaboration and assess the value of that firm's resources. As a consequence, a focal firm becomes less attractive for potential partners, to the extent that its firm-specific uncertainty goes up. That means it will become more difficult for it to find potential partners. This may accordingly amplify that firm's in-house orientation, producing a stronger decrease in its collaboration activities overall than we anticipated.[10]

Finally, we found confirmation for both Hypotheses 5a and 5b. At the portfolio level, we found that the effect size of a firm's adaptation to its IOR portfolio diversity was indeed substantively stronger for its increase in response to industry technological change, compared to its decrease in response to firm-specific technological change. In a similar vein, we found that the effect sizes of changes in its individual IOR modes were stronger for industry technological change than for firm-specific change. This confirms the general idea in prospect theory that the "fear of loss," represented in this study by industry technological change, generally proves more powerful than the "hope of gain," represented by firm-specific technological change.

From these findings, a number of conclusions follow. Our dual focus on the portfolio level and the mode level has enabled us to develop a more comprehensive understanding of how firms accomplish the major strategic task of adapting their IORs to environmental change. This dual focus allowed us to identify that firms respond to the two types of technological change in somewhat unexpected ways, that is, through stronger forms of adaptation than anticipated. Firms attempt to gain control over industry technological change by churning their portfolio of IORs, leading to loosening control at the mode level and greater adaptivity at the portfolio level. With firm-specific change, they adapt instead by reducing portfolio diversity, while cutting back on collaboration across five out of six modes. These are new insights that complement the literature, with its dominant focus on dyadic collaboration with an individual partner, in that they offer a more in-depth understanding of how firms strategically adapt: either through an increase of their boundary-spanning activities and a major overhaul of their portfolio in response to industry technological change or by moving away from collaboration overall and resorting to more internal actions in response to firm-specific change.

The question we examined in this paper on how firms adapt their external organization, as consisting of IORs, goes beyond the well-studied question of how to economize on transaction costs in view of mitigating the hazards of a specific partnership and whether, for example, a more hierarchical or more flexible form of collaboration is preferred. While the underlying issue pertains to an important tactical choice as such, that dominant perspective has typically overlooked the more strategic decision of whether to increase collaboration activities overall or decrease them and rely on a more in-house orientation instead. Our findings complement the earlier study by Beckman et al. (2004); it focused on the question of deepening versus broadening of firm networks but failed to consider the more fundamental question of whether this occurred through more or less external collaboration in the first place. Adaptation of an IOR portfolio goes beyond substituting one mode of IOR for another and is thus less about the tactical decisions regarding specific modes that has been the dominant focus in the literature and more about the strategic decisions about intensifying or diminishing collaboration activities overall and initiating highly flexible modes or relying on an in-house orientation.

In addressing the question of how firms adjust their IOR portfolio to technological change, we contribute to different bodies of literature. First, we contribute to the literature on organizational adaptation. In this literature, the major emphasis has been on firm-internal issues, such as, among other things, adjustments of standing managerial roles (Stan and Puranam, 2017), individual learning (Aggarwal et al., 2017),

[10] We thank an anonymous reviewer for pointing this out.

service offerings (Ruef, 1997), current strategy and structure (Jennings and Seaman, 1994), or internal routines (Yi et al., 2016), with no attention to the external organization of IORs. Given the fact that collaboration has become a widespread practice, in all its different forms, and is of eminent importance to firm performance and long-term survival, this is a critical topic to understand. In line with our expectations, we found that firms adapt their portfolio diversity by increasing or decreasing it. However, unexpected was the new finding that, apart from how they organize this in a portfolio of different IOR modes, firms also adapt more fundamentally by either increasing or decreasing the extent to which they rely on collaboration. Thus, we found that adaptation can also mean a de-emphasis on IORs, with a stronger internal focus instead. This suggests that the boundary between a firm's internal and external organization is permeable when it comes to adaptation of its IOR portfolio, a finding that also complements, for example, insights into how firms' CEOs respond internally to technological change (Eggers and Kaplan, 2009).

Second, we contribute to the literature on interfirm collaboration and IOR portfolios. This literature has shown that an IOR portfolio for innovation holds the promise of delivering value and enhancing performance. However, our current understanding of such portfolios and the associated performance outcomes will remain only partial, at best, without an appreciation of the adaptations in the portfolios that gave rise to such outcomes in the first place (Ahuja et al., 2012; Kantola et al., 2017; Tatarinowitz et al., 2016). By developing a more behavioral understanding of the antecedents of changes to IOR portfolios, our study argues and shows that these structures are only temporary and subject to change. This carries implications for standing insights in the IOR literature, such as on social capital. The common message from this literature is that collaboration portfolios and interfirm networks convey stable social capital, which offers social benefits (Coleman, 1988), as well as private benefits (Burt, 1992). Following our findings, which show that companies adapt more firmly and more directed than anticipated, the well-studied private and social benefits of social capital obtained from a collaboration portfolio may be more temporary and more liable to decay than is currently assumed by the dominant, static view in the literature on IORs, which has mainly emphasized the stable value flowing from these activities (e.g., Adler and Kwon, 2002; Gilsing et al., 2008; Tasselli et al., 2015; Wassmer, 2010).

Third, our study contributes by developing a micro-foundational understanding, based on prospect theory, of the antecedents of IOR portfolios and network change. In this way, we address an important void between two long-standing traditions of research, namely between networks and IORs on the one hand and behavioral theories of the firm on the other hand (Baum et al., 2005; Gavetti et al., 2012). Combining these streams of literature offers new insights to the mainstream, structural view in the network literature that has mainly emphasized the prerogative of network structure and assumed its stability but has largely ignored whether and how firms change their IOR portfolios and networks (Ahuja et al., 2012; Phelps et al., 2012; Tatarinowitz et al., 2016).

Here, our study contributes by shedding more light on the inadequately studied role of agency in IORs and networks, which refers to a firm's purposeful enactment of their IORs through creating beneficial links or dissolving unattractive or ineffective ones (Burt, 2005; Emirbayer and Mische, 1998; White, 1992). Relying on such an agency perspective is particularly useful when developing and testing theories that explain how IORs and network strategies become manifest in a dynamic context (Ahuja et al., 2012), which is the case in our dynamic, technology-based setting. Here, our study sheds more light on this by showing how firms purposefully enact the adaptation of their IOR portfolio and how this differs as a function of different types of technological change. This serves as an important complement to the dominant view in the literature that has mainly emphasized the performance outcomes of stable network traits, either in dyadic form (e.g., Gulati, 1995), portfolio form (e.g., Srivastava and Gnyawali, 2011), or network form (e.g., Gilsing et al., 2008) but has ignored how such structures come into being, and get adapted, in the first place. Our study addresses this issue, as it develops a more comprehensive, behavioral understanding of the origins of a firm's portfolio of IORs before it gives rise to the (well-established) performance outcomes.

Notwithstanding these contributions, this study is limited by its focus on large firms (although there is quite some variation in the sample with regard to firm size). Since large firms might be better able to initiate and maintain IORs, they might also be better able to adjust their IOR portfolio. As a consequence, the effects for smaller firms might be different. Future studies could aim to extend our findings by investigating how small firms adjust their IOR portfolio. In addition, the focus of this study is on the initiation of new IOR modes and the overall distribution of these modes in the IOR portfolio and assumes (as in other studies) that existing IORs discontinue after some time. Although it is difficult to obtain sufficient data on IOR discontinuations, further research is needed to understand the ways and extent to which firms actively discontinue their IOR modes in response to a changing environment.

Another interesting avenue for future research is to study what firm-internal adaptations are needed to support these external adaptations to changing environmental conditions. For example, if a firm decides to churn its IOR portfolio in response to industry technological change, what adaptations are needed to any of its internal attributes, such as to structure, managerial roles, or identity, to support this change? These topics have been studied in the realm of organizational adaptation but have remained limited to a firm-internal focus (e.g., Dutton and Dukerich, 1991; Jennings and Seaman, 1994; Stan and Puranam, 2017). An understanding of the interplay between adaptation of external and internal attributes, both in its process and performance effects, would provide a more comprehensive understanding of organizational adaptation.

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References

Abrahamson, E., Rosenkopf, L., 1993. Institutional and competitive bandwagons: using mathematical modeling as a tool to explore innovation diffusion. Acad. Manag. Rev. 18 (3), 487–517.
Adler, P.S., Kwon, S., 2002. Social capital: prospect for a new concept. Acad. Manag. Rev. 27 (1), 17–40.
Aggarwal, V.A., Posen, H.E., Workiewicz, M., 2017. Adaptive capacity to technological change: a microfoundational approach. Strateg. Manage. J. 38 (6), 1212–1231.
Ahuja, G., 2000a. Collaboration networks, structural holes, and innovation: a longitudinal study. Adm. Sci. Q. 45 (3), 425–455.
Ahuja, G., 2000b. The duality of collaboration: inducements and opportunities in the formation of interfirm linkages. Strateg. Manage. J. 21 (3), 317–343.
Ahuja, G., Soda, G., Zaheer, A., 2012. The genesis & dynamics of organizational networks. Organ. Sci. 23 (2), 434–448.
Anand, B.N., Khanna, T., 2000. Do firms learn to create value? The case of alliances. Strateg. Manage. J. 21 (3), 295–315.
Anderson, M., Nichols, M., 2007. Information gathering and changes in threat and opportunity perceptions. J. Manag. Stud. 44 (3), 367–387.
Anderson, P., Tushman, M.L., 1990. Technological discontinuities and dominant designs: a cyclical model of technological change. Adm. Sci. Q. 35 (4), 604–633.
Arora, A., Nandkumar, A., 2012. Insecure advantage? Markets for technology and the value of resources for entrepreneurial ventures. Strateg. Manage. J. 33, 231–251.
Barringer, B.R., Harrison, J.S., 2000. Walking a tightrope: creating value through interorganizational relationships. J. Manage. 26 (3), 367–403.
Baum, J., Rowley, T., Shipilov, A., Chuang, Y., 2005. Dancing with strangers: aspiration performance and the search for syndicate underwriters. Adm. Sci. Q. 50 (4), 536–575.
Beckman, C.M., Haunschild, P.R., Phillips, D.J., 2004. Friends or strangers? Firm-specific uncertainty, market uncertainty, and network partner selection. Organ. Sci. 15 (3), 259–275.
Bergh, D.D., Lim, E.N., 2008. Learning how to restructure: absorptive capacity and improvisational views of restructuring actions and performance. Strateg. Manage. J. 29 (6), 593–616.
Bromiley, 2010. Looking at prospect theory. Strateg. Manage. J. 31 (12), 1357–1370.
Burt, R., 1992. Structural Holes: The Social Structure of Competition. Harvard University

Press, Cambridge, MA.
Burt, R., 2005. Brokerage and Closure. An Introduction to Social Capital. Oxford University Press.
Caner, T., Bruyaka, O., 2016. Flow signals: evidence from patent and alliance portfolios in the US biopharmaceutical industry. Forthcoming. J. Manag. Stud.
Carayannopoulos, S., Auster, E.R., 2010. External knowledge sourcing in biotechnology through acquisition versus alliance: a KBV approach. Res. Policy 39 (2), 254–267.
Ceccagnoli, M., Hicks, D., 2013. Complementary assets and the choice of organizational governance: empirical evidence from a large sample of U.S. Technology-based firms. IEEE Trans. Eng. Manag. 60 (1), 99–112.
Chattopadhyay, P., Glick, W.H., Huber, G.P., 2001. Organizational actions in response to threats and opportunities. Acad. Manag. J. 44 (5), 937–955.
Coleman, J.S., 1988. Social capital in the creation of human capital. Am. J. Sociol. 94, 95–120.
Colombo, M.G., 2003. Alliance Form: A Test of the Contractual and Competence Perspectives. Strateg. Manage. J. 24, 1209–1229.
Cuypers, I.R.P., Martin, X., 2010. What makes and what does not make a real option? A study of equity shares in international joint ventures. J. Int. Bus. Stud. 41 (1), 47–69.
Dattee, B., Barlow, J., 2017. Multilevel organizational adaptation: scale invariance in the Scottish healthcare system. Organ. Sci. 28 (2), 301–319.
De Leeuw, T., Lokshin, B., Duysters, G., 2014. Returns to alliance portfolio diversity: the relative effects of partner diversity on firm's innovative performance and productivity. J. Bus. Res. 67 (9), 1839–1849.
Deeds, D.L., Hill, C.W.L., 1996. Strategic alliances and the rate of new product development: an empirical study of entrepreneurial biotechnology firms. J. Bus. Ventur. 11 (1), 41–55.
Dess, G.G., Beard, D.W., 1984. Dimensions of organizational task environments. Adm. Sci. Q. 29 (1), 52–73.
Duncan, R.B., 1972. Characteristics of organizational environments and perceived environmental uncertainty. Adm. Sci. Q. 17 (3), 313–327.
Dushnitsky, G., Lavie, D., 2010. How alliance formation shapes corporate venture capital investment in the software industry: a resource-based perspective. Strateg. Entrep. J. 4 (1), 22–48.
Dushnitsky, G., Lenox, M.J., 2005a. When Do Firms Undertake R&D by Investing in New Ventures? Strateg. Manage. J. 26 (10), 947–965.
Dushnitsky, G., Lenox, M.J., 2005b. When do incumbents learn from entrepreneurial ventures? Corporate venture capital and investing firm innovation rates. Res. Policy 34 (5), 615–639.
Dutton, J.E., Dukerich, J.M., 1991. Keeping an eye on the mirror: image and identity in organizational adaptation. Acad. Manag. J. 34 (3), 517–554.
Duysters, G., Lokshin, B., 2011. Determinants of alliance portfolio complexity and its effect on innovative performance of companies. J. Prod. Innov. Manage. 28 (4), 570–585.
Eggers, J.P., Kaplan, S., 2009. Cognition and Renewal: Comparing CEO and Organizational Effects on Incumbents Adaptation to Technical Change. Organ. Sci. 20 (2), 461–477.
Emirbayer, M., Mische, A., 1998. What is Agency? Am. J. Sociol. 103 (4), 962–1023.
Folta, T.B., 1998. Governance and uncertainty: the trade-off between administrative control and commitment. Strateg. Manage. J. 19 (11), 1007–1028.
Foss, N.J., Pedersen, T., Pyndt, J., Schultz, M., 2012. Innovating organization & management. New Sources of Competitive Advantage. Cambridge University Press, Cambridge (UK).
Garcia Canal, E., Valdes-Llaneza, A., Sanchez-Lorda, P., 2008. Technological flows and choice of joint ventures in technology alliances. Res. Policy 37 (1), 97–114.
Gavetti, G., Greve, H.R., Levinthal, D.A., Ocasio, W., 2012. The behavioral theory of the firm: assessment and prospects. Acad. Manag. Ann. 6 (1), 1–40.
Gilsing, V., Nooteboom, B., Vanhaverbeke, W., Duysters, G., Van den Oord, A., 2008. Network embeddedness and the exploration of novel technologies: technological distance, betweenness centrality and density. Res. Policy 37 (10), 1717–1731.
Gilsing, V., Vanhaverbeke, W., Pieters, M., 2014. Mind the Gap: Balancing Alliance Network and Technology Portfolios During Periods of Technological Uncertainty. Technol. Forecast. Soc. Change 81, 351–362.
Goerzen, A., 2007. Alliance networks and firm performance: the impact of repeated partnerships. Strateg. Manage. J. 28 (5), 487–509.
Goerzen, A., Beamish, P.W., 2005. The effect of alliance network diversity on multinational enterprise performance. Strateg. Manage. J. 26 (4), 333–354.
Granovetter, M., 1982. The strength of weak ties: a network theory revisited. In: Marsden, P.V., Lin, N. (Eds.), Social Structure and Network Analysis. Sage, Beverly Hills, CA, pp. 105–130.
Greve, H., 1998. Performance, aspirations, and risky organizational change. Adm. Sci. Q. 43 (1), 58–86.
Gulati, R., 1995. Does familiarity breed trust? The implications of repeated ties. Acad. Manag. J. 38 (1), 85–112.
Gulati, R., Garguilo, M., 1999. Where Do Interorganizational Networks Come From? Am. J. Sociol. 104 (5), 1439–1493.
Gulati, R., Singh, H., 1998. The architecture of cooperation: managing coordination costs and appropriation concerns in strategic alliances. Adm. Sci. Q. 43 (4), 781–784.
Guo, R.-J., Lev, B., Zhou, N., 2004. Competitive costs of disclosure by biotech IPOs. J. Account. Res. 42 (2), 319–355.
Hagedoorn, J., 1993. Understanding the rationale of strategic technology partnering: interorganizational modes of cooperation and sectoral differences. Strateg. Manage. J. 14 (5), 371–385.
Hagedoorn, J., Cloodt, M., 2003. Measuring Innovative Performance: Is There an Advantage in Using Multiple Indicators? Res. Policy 32 (8), 1365–1379.
Hall, B.H., Jaffe, A.B., Trajtenberg, M., 2001. The NBER patent citations data file: lessons, insights and methodological tools. In: Jaffe, A., Trajtenberg, M. (Eds.), Patents, Citations and Innovations. The MIT Press, Cambridge, MA.
Harrison, D.A., Klein, K.J., 2007. What's the difference? Diversity constructs as separation, variety, or disparity in organizations. Acad. Manag. Rev. 32 (4), 1199–1228.
Hashai, N., Kafouros, M., Buckley, P.J., 2015. The performance implications of speed, regularity, and duration in alliance portfolio expansion. Forthcoming. J. Manage.
Haveman, H., 2003. Between a rock and a hard place: organizational change and performance under conditions of fundamental environmental transformation. Adm. Sci. Q. 37 (1), 48–75.
Hitt, M.A., Hoskisson, R.E., Johnson, R.A., Moesel, D.D., 1996. The market for corporate control and firm innovation. Acad. Manag. J. 39 (5), 1084–1119.
Hrebiniak, L.G., Joyce, W.F., 1985. Organizational adaptation: strategic choice and environmental determinism. Adm. Sci. Q. 30, 336–349.
Jaffe, A.B., 1968. Technological opportunity and spillovers of r & d: evidence from firms' patents, profits, and market value. Am. Econ. Rev. 76 (5), 984–1001.
Jennings, D., Seaman, S., 1994. High and low levels of organizational adaptation: an empirical analysis of strategy, structure, and performance. Strateg. Manage. J. 15 (6), 459–475.
Jiang, R.J., Tao, Q.T., Santoro, M.D., 2010. Alliance portfolio diversity and firm performance. Strateg. Manage. J. 31 (10), 1136–1144.
Joos, P., Zhdanov, A., 2008. Earnings and equity valuation in the biotech industry: theory and evidence. Financ. Manage. 37 (3), 431–460.
Kahneman, D., Tversky, A., 1979. Prospect theory: an analysis under risk. Econometrica 47, 263–292.
Kang, J., Marhold, K., 2016. The effects of internal technological diversity and external uncertainty on technological alliance portfolio diversity. Forthcoming. Ind. Innov.
Kantola, J., Liu, Y., Peura, P., De Leeuw, T., Zhang, Y., Naaranoja, M., Segev, A., Huisingh, D., 2017. Innovative products and services for sustainable societal development: current reality, future potential, and challenges. J. Clean. Prod. 162, 1–10.
Keil, T., Maula, M., Schildt, H., Zahra, S.A., 2008. The effect of governance modes and relatedness of external business development activities on innovative performance. Strateg. Manage. J. 29 (8), 895–907.
Kogut, B., 1991. Joint ventures and the option to expand and acquire. Manage. Sci. 37 (1), 19–33.
Krackhardt, D., 1992. the strength of strong ties: the importance of philos in organizations. In: Nohria, N., Eccles, R. (Eds.), Networks and Organizations: Structure, Form and Action. Harvard University Press, Cambridge, MA, pp. 216–239.
Lee, D., Kirkpatrick-Husk, K., Madhavan, R., 2017. Diversity in alliance portfolios and performance outcomes: a meta-analysis. J. Manage. 43 (5), 1472–1497.
Li, Y., 2008. Duration analysis of venture capital staging: a real options perspective. J. Bus. Ventur. 23 (5), 497–512.
Li, J., Li, Y., 2010. Flexibility versus commitment: MNEs' ownership strategy in China. J. Int. Bus. Stud. 41 (9), 1550–1571.
Mann, R.J., Sager, T.W., 2007. Patents, venture capital, and software start-ups. Res. Policy 36 (2), 193–208.
Meyer, A., Brooks, G., Goes, J., 1990. Environmental jolts and industry revolutions: organizational responses to discontinuous change. Strateg. Manage. J. 11, 93–110.
Mone, M., McKinley, W., Barker, V., 1998. Organizational decline and innovation: a contingency framework. Acad. Manag. Rev. 23 (1), 115–132.
O'Reilly, C., Tushman, M., 2008. Ambidexterity as a Dynamic Capability: Resolving the Innovator's Dilemma. Research Paper Series. Stanford Graduate School of Business.
Ocasio, W., 1995. The enactment of economic diversity: a reconciliation of theories of failure-induced change and threat-rigidity. In: In: Cummings, L.L., Staw, B.M. (Eds.), Research in Organizational Behavior, vol17. JAI Press, Greenwich, CT, pp. 287–331.
Osiyevskyy, A., Dewald, J., 2015. Explorative versus exploitative business model change: the cognitive antecedents of firm-level responses to disruptive innovation. Strateg. Entrep. J. 9, 58–78.
Ozmel, U., Reuer, J.J., Gulati, R., 2013. Signals across multiple networks: how venture capital and alliance networks affect interorganizational collaboration. Acad. Manag. J. 56 (3), 852–866.
Patel, P., Pavitt, K., 1997. The technological competencies of the world's largest firms: complex and path-dependent, but not much variety. Res. Policy 26 (2), 141–156.
Pérez-Nordtvedt, L., Khavul, S., Harrison, D., McGee, J., 2014. Adaptation to temporal shocks: influences of strategic interpretation and spatial distance. J. Manag. Stud. 51 (6), 869–897.
Phelps, C.C., 2010. A longitudinal study of the influence of alliance network structure and composition on firm exploratory innovation. Acad. Manag. J. 53 (4), 890–913.
Phelps, C., Heidl, R., Wadhwa, A., 2012. Knowledge, networks and knowledge networks: a review and research agenda. J. Manage. 38 (4), 1115–1166.
Powell, W.W., White, D.R., Koput, K.W., Owen-Smith, J., 2005. Network dynamics and field evolution: the growth of interorganizational collaboration in the life sciences. Am. J. Sociol. 110 (4), 1132–1205.
Ruef, M., 1997. Assessing organizational fitness on a dynamic landscape: an empirical test of the relative. Inertia Thesis. Strateg. Manage. J. 18 (11), 837–853.
Sabidussi, A., Lokshin, B., De Leeuw, T., Duysters, G., Bremmers, H., Omta, O., 2014. A comparative perspective on external technology sourcing modalities: the role of synergies. J. Eng. Technol. Manag. 33, 18–31.
Sahaym, A., Steensma, H.K., Schilling, M.A., 2007. The influence of information technology on the use of loosely coupled organizational forms: an industry-level analysis. Organ. Sci. 18 (5), 865–880.
Sampson, R.C., 2007. R&D alliances and firm performance: the impact of technological diversity and alliance organization on innovation. Acad. Manag. J. 50 (2), 364–386.
Santoro, M.D., McGill, J.P., 2005. The effect of uncertainty and asset Co-specialization on governance in biotechnology alliances. Strateg. Manage. J. 26 (13), 1261–1269.
Schilling, M.A., 2009. Understanding the alliance data. Strateg. Manage. J. 30 (3), 233–260.
Schilling, M.A., Phelps, C.C., 2007. Interfirm collaboration networks: the impact of large-

scale network structure on firm innovation. Manage. Sci. 53 (7), 1113–1126.
Siggelkow, N., Levinthal, D.A., 2003. Temporarily divide to conquer: centralized, decentralized, and reintegrated organizational approaches to exploration and adaptation. Organ. Sci. 14 (6), 650–669.
Song, M., Droge, C., Hanvanich, S., Calantone, R., 2005. Marketing and technology resource complementarity: an analysis of their interaction effect in two environmental contexts. Strateg. Manage. J. 26 (3), 259–276.
Srivastava, M.K., Gnyawali, D.R., 2011. When do relational resources matter? Leveraging portfolio technological resources for breakthrough innovation. Acad. Manag. J. 54 (4), 797–810.
Stan, M., Puranam, O., 2017. Organizational adaptation to interdependence shots: the role of integrator structures. Strateg. Manage. J. 38 (5), 1041–1061.
Staw, B.M., Sandelands, L.E., Dutton, J.E., 1981. Threat rigidity effects in organizational behavior: a multilevel analysis. Adm. Sci. Q. 26 (4), 501–524.
Tasselli, S., Kilduff, M., Menges, J.I., 2015. The micro-foundations of organizational social networks: a review and an agenda for future research. J. Manage. 41 (5), 1361–1387.
Tatarinowitz, A., Sitch, M., Gulati, R., 2016. Environmental demands and the emergence of social structure: technological dynamism and interorganizational network forms. Adm. Sci. Q. 16 (1), 52–86.
Teece, D., 1986. Profiting from technological innovation: implications for integration, collaboration, licensing and public policy. Res. Policy 15 (6), 285–305.
Tushman, M.L., Anderson, P., 1986. Technological discontinuities and organizational environments. Adm. Sci. Q. 31 (3), 439–465.
Tversky, A., Kahneman, D., 1992. Advances in prospect theory: cumulative representation of uncertainty. J. Risk Uncertain. 5, 297–323.
Van de Vrande, V., 2013. Balancing your technology-sourcing portfolio: how sourcing mode diversity enhances innovative performance. Strateg. Manage. J. 34 (5), 610–621.
Van de Vrande, V., Vanhaverbeke, W., Duysters, G., 2009. External technology sourcing: the effect of uncertainty on governance mode choice. J. Bus. Ventur. 24 (1), 62–80.
Wassmer, U., 2010. Alliance portfolios: a review and research agenda. J. Manage. 36 (1), 141–171.
White, H., 1992. Agency as control in formal networks. In: Nohria, N., Eccles, R.G. (Eds.), Networks and Organizations: Structure, Form and Action. Harvard Business School Press, Cambridge, MA.
Williamson, O.E., 1981. The economics of organization: the transaction cost approach. Am. J. Sociol. 87 (3), 548–577.
Wiseman, R.M., Gomez-Mejia, L.R., 1998. A behavioral agency model of managerial risk taking. Acad. Manag. Rev. 23 (1), 133–153.
Yi, S., Knudsen, T.H., Becker, M., 2016. Inertia in routines: a hidden source of organizational variation. Organ. Sci. 27 (3), 782–800.